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Components for Management of Field Corn and Grain Sorghum Insects and Mites in the United States

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Components for Management of Field Corn and Grain Sorghum Insects and Mites in the United States

By B. R. Wiseman[1] and W. P. Morrison[2]

ABSTRACT

The corn earworm, European corn borer, corn rootworms, fall armyworm, southwestern corn borer, black cutworm, sorghum midge, greenbug, sorghum webworm, and spider mites are discussed. Control of these major pests relies, for the most part, on conventional pesticides. Alternative control will depend on filling some research, information, and education gaps. Index terms: corn, insect control, insect pests, integrated pest management, mite pests, sorghum.

INTRODUCTION

Field corn and grain sorghum are grown on more than 95 million acres in the United States. In 1978, the farm value of these crops amounted to over $16.2 billion (U.S. Department of Agriculture 1979). Corn is the principal cash grain crop in the United States and is ranked the third most important cereal food crop in the world (Luckman 1978). Sorghum ranks third as a U.S. cash grain crop and is fifth in importance as a world cereal crop (U.S. Department of Agriculture 1979). Losses to pests and the expense of protecting crops from damage are among the major costs to the farmer. Estimated losses in corn and sorghum from arthropod pest damage amount to about 10 percent of the crops annually.

The trend in insect pest control is to decrease the use of conventional insecticides, not only because of the cost but also to minimize environmental disruption and avoid the development of pesticide resistance. In 1952, only 1 percent of the total corn acreage was treated with insecticides (table 1). However, steady increases in pesticide usage have occurred since that time, and in 1976, 38 percent of all corn acreage was treated. The amount of pesticides used for control of corn insects has more than doubled since 1964, from 15.7 million pounds up to an estimated 32 million pounds in 1976. Turpin and Maxwell (1976) reported that in Indiana corn acreage treated with a soil insecticide increased from 10 percent in 1960 to 40 percent in 1972. They also stated that the actual need for soil insect control may have actually decreased during the same period and that research showed that less than 10 percent of the corn acreage needed a soil insecticide from 1972 to 1974. However, most decisions on control in the past were made by the grower without input from scouting reports. But Glass (1975) pointed out that in some instances when insect pests are monitored closely, more insecticide may be applied because economic injury levels are determined more frequently. Insecticides were used sparingly on sorghum until 1971 (table 1). During that year, 39 percent of the total acreage

[1]Research entomologist, Southern Grain Insects Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Tifton, Ga. 31713.

[2]Former extension entomologist, Texas A&M University, Lubbock, Tex. 79401. Present address: Department of Entomology, Texas Tech University, Lubbock, Tex. 79401.

Table 1.—Field corn and grain sorghum acreage treated with insecticides in the United States, 1952-76

Year	Acreage treated (percent)	
	Corn	Sorghum
1952	1	NA
1958	6	NA
1966	33	2
1971	35	39
1976	38	27

NA, Not available.

Sources: Fox et al. 1968, Andrilenas 1975, and personal communication, P. A. Andrilenas, 1979.

Table 2.—Amount of insecticide used on field corn and grain sorghum in the United States, 1964-76

Year	Million pounds of active ingredient	
	Corn	Sorghum
1964	15.7	NA
1966	23.6	NA
1971	25.5	5.7
1976	32.0	4.6

NA, Not available.

Sources: Fox et al. 1968, Andrilenas 1975, and personal communication, P. A. Andrilenas, 1979.

received insecticide treatment, and 5.7 million pounds of insecticides were used (table 2). Most of this increase was probably due to the greenbug biotype attacking sorghum, which was not serious until about 1968. By 1976 treated acreage decreased, and only 27 percent of the total sorghum acreage was treated with insecticides. Pounds used decreased to 4.6 million. This drop may have been due, in part, to the advent of greenbug-resistant hybrids being grown in 1976 and the implementation of grain sorghum pest-management programs.

"Integrated pest management" (IPM) is not new; it has been in existence since the mid-1950's and even much earlier when other terms were used (Knipling 1966; National Academy of Sciences 1969, 1975; Glass 1975; Smith 1978). Integrated pest management has been defined (Glass 1975) as a "pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury." Pedigo (1975) suggested that some of the strategies that may be applied to managing corn and sorghum pests for a pest management program may be compared with those of constructing a building. Species biology, population sampling, and artificial rearing of the insect are valuable components. As a broader base, bioeconomics and population dynamics are equally important. For the tactics used in population suppression, the individual components of the integrated approach were used; for overall plant protection, it was the use of all available components in one package that was of utmost importance.

Kendrick (1978) stated that the key ingredient of integrated control is information. We must know the various ingredients of managing each corn and sorghum pest and the consequence of any intergrated effort to manipulate it as well as the remaining pest complex. This technology may be disseminated and adopted for on-farm use before we can realize the effects of the various combinations of control measures. However, even then, the effectiveness and efficiency of various pest-management strategies need to be monitored. Our challenge today is to provide solutions and efficiently utilize these with scouting programs and management consultants to minimize insect losses in corn and sorghum without sacrificing environmental quality. Complete control of our corn and sorghum insect pests is unrealistic and incompatible with today's insect-management approaches of managing the pests at levels below the economic threshold. Prior to initiation of new or more ambitious research programs to determine the best pest-management components, we need to become familiar with the current pest-management practices used for some key corn and sorghum arthropod pests.

We report here some of the aspects of integrated contol practices for several key corn and sorghum insect and mite pests and point out some of the more important needs for managing these pests below the economic threshold level. The opinions expressed are those of the authors and do not constitute an official opinion by the U.S. Department of Agriculture. Economic

Table 3.—Field corn production and value in the United States, 1959-78

Year	Acres planted (1,000)	Yield (bushels per acre)	Value of production ($1,000)
1959	82,742	53.1	4,013,126
1965	65,171	74.1	4,754,199
1970	66,863	72.4	5,514,350
1977	83,568	90.7	12,944,467
1978[1]	79,719	101.2	14,888,952

[1]Preliminary.

Source: U.S. Department of Agriculture 1979.

Table 4.—Estimated annual loss of field corn crop to selected insects in the United States

Insect	Loss (percent)
Corn earworm	2.5
European corn borer	2.0
Corn rootworms	2.0
Fall armyworm	2.0
Southwestern corn borer	1.0
Black cutworm	1.0
Mites and other insects	1.5
Total	12.0

Source: U.S. Agricultural Research Service 1976.

thresholds for the various pests and the acreages involved in the pest-management program were the result of a survey in 1978, by the authors, of pest-management specialists in the extension services of various participating States.

FIELD CORN

Field corn is the most valuable crop grown in the United States (U.S. Department of Agriculture 1979). Although the amount planted has increased only about 2 million acres since the bumper crop of 1959, the acreage since 1965 has steadily increased, and the value of the total corn crop has more than tripled since 1959 to over $14 billion (table 3).

Many species of insects attack corn, and many are of economic importance. Several excellent corn-insect publications are available; probably one of the most reviewed is Dicke's (1977). He describes the biology, feeding habits, and control of key corn insects as well as secondary and occasional ones. Some of the most important are given in table 4.

Corn Earworm

The corn earworm, *Heliothis zea* (Boddie), is distributed over the entire corn-growing area of the United States. Earworms may feed on the whorl leaves and on the emerging tassel, but they most frequently feed on the tips of the ears (Dicke 1977). Losses caused by earworms have been estimated at 2.5 percent annually (table 4). Only three States (Alabama, Oklahoma, and Texas) reported in 1976 in the cooperative insect report that corn earworm losses were estimated at 1.5 percent, or an average of 1.43 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). No economic thresholds have been developed for the corn earworm in field corn (Sparks and Mitchell 1979).

Few if any chemicals are used for earworm control in field corn (table 5). The primary control measure is planting of resistant hybrids, followed by cultural practices (early planting) and reliance on natural entomophages (parasites and predators). The plant resistance that is available is simply a resistance to damage, and the mechanism has been described as tolerance (Wiseman et al. 1972). Thus, the resistant corns simply tolerate the corn earworm. These hybrids are producing as many earworms as the susceptible corns, and the corn-produced earworms cause damage in other cropping systems. Of the several predators and parasitoids that inhabit cornfields, *Orius insidiosus* (Say) is of particular interest, since it will forage down into the silk channel for young larvae.

In the future, the development of highly resistant germplasm will become more important (tables 6 and 19). Hybrids with antibiotic properties or hybrids that do not attract earworms will not only have an impact on populations in corn but, more importantly, in crops such as cotton and sorghum. The planting of early-maturing hybrids will continue to be important. Of potential methods, the use of kairomones to manage earworm predators and parasites (Lewis et al. 1975), the manipulation of naturally occurring predators such as *Orius insidiosus*, the use of *Heliothis* nuclear-polyhedrosis virus (Hamm and Young 1971) and other patho-

Table 5.—Principal methods of controlling various field corn insects and mites in the United States, ranked by importance

Insect	Control methods in simultaneous use[1]			
	Conventional insecticides	Cultural practices	Resistant varieties	Predators and parasites
Corn earworm	....	2	1	3
European corn borer	3	2	1	4
Corn rootworms	1	2	3	....
Fall armyworm	2	1	....	3
Southwestern corn borer	2	1	....	3
Black cutworm	2	1	....	3
Mites	1	2	....	3

[1]For each insect, rank (1=most used) based on a survey of selected State corn and sorghum research workers by the authors. Pathogens, pheromones, genetic manipulation, attractants, repellents, light traps, sterilants, and other "biological" methods are not used. "Predators and parasites" refers to naturally occurring organisms, not to artificially introduced organisms.

Table 6.—Potential methods of controlling various field corn insects and mites in the United States, ranked by importance in an integrated pest-management system

Insect	Control method[1]					
	Conventional insecticides	Cultural practices	Resistant varieties	Predators and parasites	Pathogens	Other[2]
Corn earworm	6	2	1	3	4	5
European corn borer	4	2	1	5	3	6
Corn rootworms	2	1	3	6	5	4
Fall armyworm	2	1	3	4	5	6
Southwestern corn borer	4	2	1	3	5	6
Black cutworm	2	1	5	6	3	4
Mites	2	1	3	4	5	6

[1]For each insect, estimates of importance (1=most important) of control methods are based on survey of selected corn and sorghum research workers by the authors.
[2]Pheromones, genetic manipulation, attractants, repellents, light traps, sterilants, and other "biological" methods.

gens, disruption or manipulation of pheromonal communication in earworms (Mitchell et al. 1975, Sparks et al. 1979), release of artificially sterilized *Heliothis* moths into natural populations, and the use of synthetic pyrethroid insecticides need to be investigated.

European Corn Borer

The European corn borer, *Ostrinia nubilalis* (Hübner), is distributed from the East Coast through the Corn Belt into the Great Plains and as far south as the Texas Panhandle and northern Florida. There are generally two generations of borers a year, but in the southernmost part of the range, there are several generations. The first generation feeds on the whorl tissue, and the second on the leaf sheath and collar, and bores into the stalk (Dicke 1977). Losses caused by the European corn borer have been estimated at 2 percent annually (table 4). In 1976, only five States (Illinois, Kentucky, Minnesota, North Dakota, and Virginia) reported in the cooperative insect report losses due to European corn borer of 3.8 percent, or an average of 5.19 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Several economic thresholds have been proposed for first-brood corn borers, varying from 35 to 75 percent of the damaged plants with live larvae present

Table 7.—Economic thresholds for the European corn borer in field corn, by State

State	Control is necessary when— 1st-brood feeding damage affects— (% of plants)	2d brood has—
Arkansas	75	([1]).
Delaware	50	([1]).
Georgia	50	([1]).
Illinois	35	1 egg mass per plant.
Indiana	[2]50	1 egg mass per plant.
Kansas	75	([1]).
Kentucky	[2]50	([1]).
Maryland	50	([1]).
Minnesota	35	([1]).
Missouri	50	Egg masses on 40%-50% of plants.
Ohio	50	([1]).

[1]Information not reported in survey response.
[2]Live larvae must be present.

(table 7) to that proposed by Chiang (1973), 50 egg masses per 100 plants.

The controls for European corn borers are the use of resistant varieties, cultural methods, and insecticides (table 5). Chiang (1976) reported that overwintering corn borers could be reduced by early harvest and stubble destruction. Planting of resistant varieties is effective in suppressing first-generation corn borers. (Resistant varieties were planted on some 21.5 million acres in 1975 (Schalk and Ratcliff 1976).) On susceptible varieties, insecticides are recommended to control heavy populations of first-brood borers although little additional benefit is realized on resistant varieties (Robinson et al. 1978). The available resistance is ineffective against second-brood borers, and insecticides must be utilized when populations exceed the economic threshold. During some years predators, parasites, and pathogens reduce borer populations.

The primary component of European corn borer management in the future (tables 6 and 19) will be increased plant resistance to first-generation borers and particularly to second-generation borers. Highly resistant inbreds can reduce the first-generation population by 89 percent, but resistance to the second generation is not as great (Guthrie et al. 1960). Presently, only one parasite, *Macrocentrus grandii* Goidanich, is sometimes found at densities high enough to be effective in suppressing corn borer populations. Hill et al. (1978) reported that five exotic parasite species of the European corn borer had been introduced into Nebraska. Three of the five species became established, but, except for localized populations, the introduced parasites have been of minor importance. A sex pheromone of the corn borer has been isolated and synthesized, but much more work will be required before it can be used practically (Klun and Robinson 1971). Experimentation by Lewis and Lynch (1976; Lynch and Lewis 1976) on a combination of resistant varieties and a pathogen has been successful. They concluded that, if the technology were available to introduce *Nosema pyrausta* (Paillot) into a large enough segment of the borer population, the effect of this protozoan on population suppression could be highly effective. Hill and Gary (1979) reported that *N. pyrausta* reached epizootic proportions twice in 16 years in Nebraska and that reduced corn borer populations followed. New types of chemical insecticides cannot be overlooked as potentially effective tactics against European corn borers. The new pyrethroids could possibly be used in combination with other controls.

Corn Rootworms

The northern corn rootworm, *Diabrotica longicornis* (Say); the southern corn rootworm, *D. undecimpunctata howardi* Barber; and the western corn rootworm, *D. virgifera* LeConte, are generally problems only in the Corn Belt. The larvae usually feed on young root hairs and lateral roots. The adults feed on the flowers of other plants but may injure corn by feeding on the silk, preventing pollination. There is only one generation annually (Dicke 1977). Losses caused by the rootworm complex have been estimated at 2 percent annually (table 4). Of the six States reporting losses in 1976 (Illinois, Minnesota, North Dakota, Oklahoma, Wisconsin, and Indiana) in the cooperative insect report for corn rootworms, losses were established at 7.6 percent, and five States reported losses due to corn rootworm larvae at 9.0 percent, or an average of 8.1 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Only two States have established economic thresholds for the larvae, three larvae per plant (table

Table 8.—Economic thresholds for corn rootworms in field corn, by State

State	Control is necessary when—		
	No. adult beetles per plant is—	*Or*	No. larvae per plant is—
Illinois	5		3
Indiana	5		3
Kansas	1		([1])
Maryland	5		([1])
Minnesota	1		([1])
Missouri	1		([1])
Ohio	5		([1])

[1]Information not reported in survey response.

8). Adult thresholds range from one to five adults per plant at silking (for suppressing overwintering populations). Wilde (1978) gives an excellent guide for detecting economically damaging populations of corn rootworms.

Integrated management tactics available for corn rootworms have been reported by Chiang (1976). Cultural controls, plant resistance, and insecticides are most commonly employed for suppression (table 5). The percentage of stalks affected by the rootworm is significantly less in plots tilled in the fall than in those tilled in the spring. Also, the application of manure assists in increasing densities of predaceous mites. Rotation with soybeans is a practical cultural-control method (Wilde 1978). Insecticides are usually preventive, especially when crop rotation is not practical. Tolerant corn hybrids that resist rootworms are available to farmers. Tolerance in hybrids, which is due primarily to a large, deep root system, is difficult to measure, and the results are even more difficult for the farmer to see; often growers will use preventive insecticide applications even though they have planted resistant hybrids. However, if adult counts were monitored during the previous year at the time of oviposition, decisions may be made for targeting soil insecticides in infested fields.

Integration of several control methods into a rootworm-management system is possible (table 6). Various methods might be used against more than one corn pest by breeding lines or hybrids with multiple resistance (Chiang 1976). Another promising component of control is sex pheromones (Bartell and Chiang 1977). One pheromone used with extenders is effective in attracting males of both western and northern species for up to three weeks (U.S. Agricultural Research Service 1976). Some of the newer insecticides could replace the relatively persistent insecticides currently used. The synthetic pyrethroids could be used in adult control or, as Chiang (1976) suggested, insecticides that are effective against both rootworms and corn borers could be used where possible.

Fall Armyworm

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is an especially damaging pest of corn in the South; losses in 1975 in Georgia alone were estimated at over $20 million. Periodically, it spreads to the southern part of the North-Central United States. Young larvae skeletonize the leaves of plants; older larvae can completely destroy small plants and strip larger ones (Luginbill 1928). We have found that an entire crop may be destroyed when populations are high. Losses attributed to the fall armyworm have been estimated at 2 percent annually (table 4). Of the three States reporting losses in 1976 (Alabama, Illinois, and Oklahoma) in the cooperative insect report, 4.9 percent was attributed to the fall armyworm, or an average of 2.54 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Few economic threshold studies have been conducted. Most States recommend treating when 50 percent of the plants show damage in the whorl stage. No threshold exists for small and mature plants.

Integrated control approaches to the fall armyworm problem generally should consider losses due to early whorl feeding, ear feeding, and particularly to corn planted as a late crop. Early plantings in the South avoid much of the fall armyworm damage, but when heavy populations occur, insecticides are used extensively. There are few hybrids with fall armyworm resistance. (The ones released to date are tropical and may be competitive with hybrids currently used for forage.) Natural predators and parasites assist in limiting damage to some extent.

Future controls will depend heavily on both cultural and chemical methods and must be based on biological approaches (table 6). Study of armyworm biology (overwintering, for example) should help us to predict serious infestations of the pest. Producing resistant germplasm (Scott et al. 1977) will have to rely on

Table 9.—Economic thresholds for the southwestern corn borer in field corn, by State

State	Control is necessary when infestations of eggs or small larvae reach—(% of plants)
Arkansas	25
Kansas	([1])
New Mexico	25
Oklahoma	25
Texas	35

[1]Information not reported in survey response.

Table 10.—Economic thresholds for the black cutworm in field corn, by State

State	Control is necessary when—		
	Plant stage is—	*Or*	Percentage of plants cut is—
Delaware			3
Illinois			3
Indiana	Complex system		
Kentucky	Up to 4 leaf		3
Maryland	Complex system		
Minnesota			3
Missouri			6–8
North Carolina			5
Ohio			3

increased efforts to rear armyworms, as outlined by Wiseman and Davis (1979). If multiple cropping of corn or late planting of corn is practiced, then resistant hybrids must be chosen and combined with proper timing of insecticide applications at the proper plant-growth stages (H. R. Gross, Jr., personal communication). Work on predators, parasites, and pathogens is essential. Selective chemicals could be used in conjunction with other control methods. Pheromones (Sekul and Sparks 1976) and sterility may also fit into the overall integrated approach.

Southwestern Corn Borer

The southwestern corn borer, *Diatraea grandiosella* (Dyar), is found in 16 Southwestern and Southern States, ranging from Arizona to Tennessee (U.S. Animal and Plant Health Inspection Service 1976). The larvae may produce four types of injury to corn: leaf feeding (whorl damage), "deadheart," stalk tunneling, and stalk girdling (Arnold et al. 1970). Losses caused by southwestern corn borers have been estimated at 1 percent annually (table 4). Of the four States reporting losses in 1976 (Alabama, Kentucky, Oklahoma, and Texas) in the cooperative insect report, 12.7 percent was due to the southwestern corn borer, or 9.68 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Economic thresholds for the southwestern corn borer ranged from none established to 35 percent of the plants infested with eggs or small larvae (table 9). Certainly, this range of opinion demonstrates the need for more research in this area.

Control has centered largely on a combination of cultural and chemical methods (Posten et al. 1978; table 5). Stubble destruction increases mortality in overwintering larvae by exposing them to cold (Arnold et al. 1970), but soil erosion makes stubble destruction impractical in some sandy areas. Early planting has been advocated in Tennessee (Bennett et al. 1964). Also, early harvest to escape "girdling" by the borers and eventual lodging of plants is recommended (Poston et al. 1978).

Cultural manipulations, plant resistance, predators and parasites, pathogens, genetic manipulation, pheromones, and new insecticides are areas needing study. Research on resistant hybrids is promising (Scott and Davis 1976, Barry and Darrah 1978). Studies involving planting dates, crop rotation, and other cultural practices should not be neglected because cultural controls usually do not involve additional costs to the grower. All controls, even though they seem of little importance at present, can be used in conjunction with the resistant hybrids. If we observe what has happened in the Corn Belt with the production of European corn borer-resistant hybrids (that resistant varieties are the principal control method), then similar efforts in southwestern corn borer research and the production of resistant germplasm should produce similar results.

Black Cutworm

The black cutworm, *Agrotis ipsilon* (Hufnagel), is becoming more of a problem every year throughout the Corn Belt. The incidence of cutworm larvae in cornfields is usually dependent on the population present in the previous season and the practices followed for seedbed

preparation (Dicke 1977). Losses caused by the black cutworm are estimated at 1 percent annually (table 4). Of the four States reporting losses in 1976 (Illinois, Kentucky, Minnesota, and North Dakota) in the cooperative insect report, 11.3 percent was attributed to the cutworms or an average of 5.06 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Few clear-cut thresholds have been developed for black cutworms (table 10). Archer and Musick (1977a, 1977b) used baits to detect the presence of larvae, then estimated the population and determined the cutting potential (damage potential) based on the larval stage and plant-growth stage.

The only methods presently used for control of black cutworms are early spring plowing (to control the weeds on which larvae establish) and the use of insecticides (table 5). Alternative controls will depend to a large degree on new studies of cutworm biology, the development of refined thresholds, and the integration of black cutworm controls with controls for insects such as the European corn borer and corn rootworms.

Mites

Spider mites, primarily the twospotted spider mite, *Tetranychus urticae* Koch, and the Banks grass mite, *Oligonychus pratensis* (Banks), are becoming increasingly important to the production of some 2 million acres of corn in the drier and warmer areas of the western Great Plains. Losses caused by these mites on corn have been estimated at 0.5 percent annually (table 4). Only Oklahoma reported losses of 2.1 percent in 1976 for the cooperative insect report due to mites, or an average of 1.98 bushes per acre (U.S. Animal and Plant Health Inspection Service 1978). The economic threshold for spider mites is not well defined. Several State guides say that chemical control should begin when the mites have colonized up to the middle third of the plant.

The only current controls (table 5) are miticides and several predaceous arthropods (Owens et al. 1976). Delayed planting can lower phytophagous mites, decrease damage, and increase yields significantly (Schweissing 1969, 1973). However, Owens et al. (1976) point out that delayed plantings are risky; early frosts may cause losses. In their work, early-maturing hybrids were of no benefit since they received more damage than did the full-season lines. Cultural manipulations, plant resistance, and biological studies must be stressed as important management strategies for the future (table 6). Since mites have developed resistance to presently used miticides in some areas (Ward and Tan 1977), replacement chemicals must be sought.

Summary

Corn crops are being protected from insect pests mainly by the use of resistant hybrids, insecticides, and good cultural practices. Watson et al. (1975) have stated, "Owing to the general lack of parasites, predators, and disease pathogens of the major corn pests, IPM has had to rely heavily on cultural practices to reduce the damage potential of many pest species." During some years, naturally occurring biological control agents may help in reducing some pest populations. Integrated control of corn pests has received greater emphasis in recent years as indicated by the review of Dickson (1975) and Chiang (1978) and 17 States (based on survey by authors) participating in the corn IPM programs.

Despite the interest in and implementation of integrated pest-management programs in corn, conventional chemical pesticides remain the predominant control employed by farmers for some key pests. Only cotton exceeds corn in pesticides applied to crops in the United States (Huffaker and Croft 1978). Chiang (1978) stated that for the European corn borer and the corn rootworm, chemical control, host-plant resistance, and certain cultural methods were the most effective, economical, and practical control measures, while biological control and innovative approaches involving genetics, pheromones, and light response were either less effective, economical, or practical. It must be emphasized that in 1976 the scientific man-years for corn were 24.6 for the U.S. Agricultural Research Service (ARS) and 19.0 for the State Agricultural Experiment Stations (SAES). This contrasts to 55.5 and 24.5 for cotton in ARS and SAES, respectively (U.S. Agricultural Research Service 1976). To reduce the dependence on chemical control, greater research emphasis will need to be placed on investigating and developing all other management components.

Reducing insect losses in corn depends to a large extent on individual growers and their

Table 11.— Cooperative extension service pest-management programs in field corn, by State, 1978[1]

State	Acres in program	State	Acres in program
Alabama	1,695	Mississippi	
Delaware	30,000	Missouri	16,500
Illinois	50,000	Nebraska	
Indiana	59,150	New Hampshire	
Iowa		New Jersey	
Kansas		North Carolina	4,500
Kentucky	7,500	Ohio	35,000
Maryland	2,000	Texas	9,800
Minnesota			

[1]Some States indicated participation but did not include scouted acreage.

ability to manage insect problems (Turpin and Maxwell 1976). The cooperation of many farmers is necessary for success areawide. Success depends on their ability to select the best planting dates, the best cultural practices, and the most resistant hybrids, and to enlist the assistance of pest-management specialists. As pointed out by Turpin (1974), economic threshold research for corn insects has lagged behind similar research on other crops. Only 1 scientific man-year in ARS is presently devoted to threshold research for cereal crops (U.S. Agricultural Reseach Service 1976). However, many States have, to a large degree, workable thresholds for several insect pests. As stated by Luckman (1978), "Corn is protected from insect pests mainly by use of insecticides, by cultural practices, and by insect-resistant varieties ....Much uncertainty about other controls, economic injury levels, economic thresholds, and pest detection/measurement/prediction can be removed by research that truly addresses the needs of pest management."

In 1978, at least 17 States (based on the survey, by the authors, of extension personnel in the corn-producing States) participated in some phase of an insect pest-management program involving corn (table 11). Several of these cooperative extension service programs are pointing out deficiencies in research programs in such areas as basic biological information, population estimation techniques, economic threshold or injury levels, and selective pesticides and rates. However, the IPM programs have caught the attention of farmers and are creating an awareness of the benefits of using sound pest-control practices.

GRAIN SORGHUM

Sorghum is the third most important cereal crop in the United States, ranking behind corn and wheat (U.S. Department of Agriculture 1979). Sorghum acreage has fluctuated between 17 million and 20 million acres over the past two decades, but the value of the crop has steadily increased (table 12). Several key insects attack sorghum. These are listed in table 13, along with an estimated percentage loss attributable to each insect (U.S. Agricultural Research Service 1976). Young (1970) reported that, of the some 100 insect species occurring on sorghum throughout the world, only 10 percent have been studied in any detail. He reviewed existing information on the more important insects and mites that occur on grain sorghum worldwide. Young and Teetes (1977) later included geographic distribution, pest status, nature of damage, and economic thresholds.

Early in the development and production of grain sorghum hybrids, the grower had access to only a few pest-managment methods. Very

Table 12.—Grain sorghum production and value in the United States, 1959-78

Year	Acres (1,000)	Bushels/acre	Value ($1,000)
1959	19,508	36.1	472,078
1965	17,079	51.8	659,146
1970	16,957	50.4	779,630
1977	16,993	56.3	1,433,991
1978[1]	16,483	55.1	1,444,654

[1]Preliminary.

Source: U.S. Department of Agriculture 1979.

Table 13.—Estimated annual loss of grain sorghum crop to selected insects in the United States

Insect	Loss (percent)
Sorghum midge	4.0
Greenbug	2.5
Fall armyworm and corn earworm	1.5
Sorghum webworm	.5
Mites	.5
Total	9.0

Source: U.S. Agricultural Research Service 1976.

Table 14.—Economic thresholds for the sorghum midge in grain sorghum, by State

State	Control is necessary when—		
	No. midges per head is—	*And*	Bloom stage is—
Alabama	>2		10%.
Georgia	1		All bloom stages.
Kansas	1-2		(Not reported.)
Missouri	>1		(Not reported.)
Texas	1		25%-30%.

Sources: Bottrell 1971, Young and Teetes 1977.

often the crop was produced on marginal land, and the cost of insecticidal treatments could not be justified. Cultural controls existed in the form of early, uniform planting and crop rotation. Most of these could not be practiced because of the set pattern of the farming practices associated with grain sorghum production (Bottrell 1971). However, as pointed out by Bottrell (1971), the situation is much different today. Insect control, like other practices of crop management, has become a regular part of the grower's overall scheme of grain sorghum production. Grain sorghum producers are more aware of insect problems and how to deal with them.

Although grain sorghum insects have received little research support, several pest-management programs are currently available for use. The Texas Agricultural Extension Service has published (1979) an excellent guide for managing sorghum pests in Texas.

Sorghum Midge

The sorghum midge, *Contarinia sorghicola* (Coquillett), is the most damaging of all sorghum insects. Generally found wherever sorghum is grown, the most damaging populations occur from Oklahoma, Arkansas, and Tennessee southward. The damage is often observed as "blasted" or "sterile" heads. Losses caused by the midge have been estimated at 4 percent annually (table 13). Of the three States (Arkansas, Oklahoma, and Texas) reporting losses in 1976 for the cooperative insect report, 4.2 percent was due to the sorghum midge, or an average of 2.42 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Economic thresholds in use are one to two adults per head (table 14).

Current integrated controls have been discussed by Bottrell (1971) and Teetes (1976). Cultural controls are generally the most frequently recommended practice for escaping midge damage (table 15). Thomas (1969), Wiseman and McMillian (1969), and Summers et al. (1976) recommended for Texas, Georgia, and California, respectively, uniform early plantings so that flowering occurs over a relatively short period of time to escape the late-season buildup of damaging midge populations. The Texas Agricultural Extension Service (1979) has provided a guideline for estimated latest sorghum flowering most likely to escape significant midge damage. If late plantings of sorghum are made, such as often happens in the Southeast, reliance on insecticidal controls may be necessary.

Until recently, the only management tools available were chemical and cultural. Now, plant resistance is being implemented since the release of a midge-resistant line, SGIRL-MR-1, in 1971 (Wiseman et al. 1973), the discovery of midge-resistant germplasm in Texas (Johnson et al. 1973), and the release of 'TAM 2566' (Johnson 1975). In the future, early planting, insecticides, and resistant hybrids will be the chief control methods (table 16). Midge parasites have had little effect on regulating populations in Georgia (Wiseman et al. 1978), and as pointed out by Holcomb (1970), the use of natural enemies as the sole means of controlling pests will seldom succeed because of the natural lag between the increasing pest population and time required for the enemy to reduce the pest.

Table 15.—Principal methods of controlling various grain sorghum insects and mites in the United States, ranked by importance

Insect	Control methods in simultaneous use[1]			
	Conventional insecticides	Cultural practices	Resistant varieties	Predators and parasites
Sorghum midge	2	1	....	....
Greenbug	3	4	1	2
Fall armyworm and corn earworm	3	1	....	2
Sorghum webworm	2	1	....	....
Mites	1	....	....	2

[1]For each insect, rank (1=most used) based on a survey of selected State corn and sorghum research workers by the authors. Pathogens, pheromones, genetic manipulation, attractants, repellents, light traps, sterilants, and other "biological" methods are not used. "Predators and parasites" refers to naturally occuring organisms, not to artificially introduced organisms.

Table 16.—Potential methods of controlling various grain sorghum insects and mites in the United States, ranked by importance in an integrated pest-management system

Insect	Control method[1]					
	Conventional insecticides	Cultural practices	Resistant varieties	Predators and parasites	Pathogens	Other[2]
Sorghum midge	2	1	3	4	6	5
Greenbug	4	3	1	2	6	5
Fall armyworm and corn earworm	5	1	3	2	4	6
Sorghum webworm	2	1	5	4	3	6
Mites	1	2	3	4	5	6

[1]For each insect, estimates of importance (1=most important) of control methods are based on survey of selected corn and sorghum research workers by the authors.
[2]Pheromones, genetic manipulation, attractants, repellents, light traps, sterilants, and other "biological" methods.

However, augmentation of parasite populations early in the season could have a practical effect.

Unique breeding procedures may be required to produce sorghum hybrids with a substantial level of resistance to the midge. It appears that resistance is recessive and is often masked or reduced in hybrid combinations. Thus, adequate levels of resistance will be required from each parent.

Greenbug

The greenbug, *Schizaphis graminum* (Rondani), identified as biotype "C" (Harvey and Hackerott 1969, Wood 1971) occurs in about all areas of the United States where sorghum is produced (Teetes 1976). The greenbug feeds on the underside of the leaves and on the stalk and head, sucking the plant sap and injecting a toxin that may cause death of the leaves if enough greenbugs are present. Heavily infested plants may be killed. Losses caused by the greenbug are estimated at 2.5 percent annually (table 13). Of the five States (Arkansas, Illinois, New Mexico, Oklahoma, and Texas) reporting losses in 1976 for the cooperative insect report, 5.3 percent was due to the greenbug, or an average of 3.17 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978). Various economic thresholds have been reported (table 17).

The controls for reducing greenbug damage are as complete as those for any insect (table

Table 17.—Economic thresholds for the greenbug in grain sorghum, by State

State	Control is necessary when— Sorghum is (has)—	And condition is—
Arizona	Seedling	Colony expanding.
	>6"	2 bottom leaves killed.
Arkansas	*Same as Texas, which see.*	
Iowa	Seedlings up to 6"	1 greenbug per plant.
	6" to 18"	2 bottom leaves brown and greenbugs on upper leaves.
	Heading	4 bottom leaves brown and colonies on upper leaves.
Kansas	0–4 live leaves	25 greenbugs per plant.
	3–6 live leaves	50–150 greenbugs per plant.
	5–8 live leaves	150–300 greenbugs per plant.
	8–10 live leaves	300–700 greenbugs per plant.
	10–12 live leaves	700–800 greenbugs per plant.
	Late whorl to milk	1,000 greenbugs per plant.
Missouri	Up to 3–4 leaves	>1 greenbug per plant.
	4–6 leaves	>1 colony per plant.
	6 leaves to preboot	1 dead leaf per plant.
	Preboot to head emergence	1–2 dead leaves per plant.
	Head emergence to maturity	3–4 dead leaves per plant.
New Mexico	*Same as Texas, which see.*	
Oklahoma	*Same as Texas, which see.*	
Texas	Up to 6"	Visible damage.
	6" to preboot	Red spotting and before any leaf killed.
	Preboot to heading	Before death of any leaves.
	Heading to hard dough	2 dead leaves.

15). Plant resistance, cultural practices, insecticides, and predators and parasites all have been used together in managing greenbug populations. One cultural component that could be used effectively is greenbug-resistant wheats which could reduce the number of greenbugs migrating to young sorghum. Teetes (1976) stated that treatments with selective insecticide rates are useful in conserving and manipulating entomophages. Resistant grain sorghum hybrids have been commercially available since 1976 (Teetes 1976). The principal mechanism of the resistance is tolerance: the resistant hybrids tolerate greenbugs while populations of natural predators and parasites increase. Teetes (1976) found that, by August 15, parasites had brought the greenbug population in check on the Texas High Plains. Martin and Wiseman (unpublished data) found a similar occurrence in Georgia; entomophages overcame the greenbug populations by late July. Effective releases of parasitoids have been made and reported by Starks et al. (1976).

Future programs (table 16) should stress education of growers and implementation of existing methods. New grain sorghum hybrids with greater resistance are continually being produced and should be tried. This resistance should contain adequate levels of tolerance, and combined with lower levels of antibiosis and nonpreference will prevent the selection of new biotypes of greenbugs. Emphasis also should be given to producing wheats with higher levels of resistance to the greenbug; such wheats will reduce early-season greenbug populations in sorghum. New insecticides will be required, as several currently registered organophosphates are ineffective because of resistant greenbugs, designated biotype "D" (Teetes et al. 1975). Even though the greenbug-sorghum relationship is one of the better examples of the use of integrated controls, there are always areas for improvement.

Fall Armyworm and Corn Earworm

The distribution of the fall armyworm and the corn earworm generally coincides with the areas of sorghum production, especially in

years of high insect populations. Damage usually consists of ragging of whorl leaves and hollowed-out kernels as a result of feeding on the developing head. Losses caused by the fall armyworm and corn earworm in sorghum are estimated at 1.5 percent annually (table 13). Of the three States (Illinois, Oklahoma, and Texas) reporting losses in 1976 for the cooperative insect report, 1.1 percent was due to the fall armyworm-corn earworm complex, or an average of 0.33 bushel per acre (U.S. Animal and Plant Health Inspection Service 1978). Control of both insects should begin, according to Teetes and Wiseman (1979) and Young and Teetes (1977), when a mean of two larvae per head is found. Henderson et al. (1966) found that two fall armyworm larvae per whorl (from the six-leaf stage to boot stage) caused a 10.4-percent reduction in yield.

Current integrated controls are not clearly recognized (table 15). However, some work (Teetes 1976) indicates that the use of early plantings of hybrids with open (noncompact) heads is helpful in suppressing corn earworms. Natural predators and parasites, particularly *Orius insidiosus*, are very good against corn earworms.

Cultural management practices will remain very important in future integrated controls (table 16); however, use of predators, parasites, and possibly pathogens will increase in importance. As a result of the buildup of entomophages on greenbug-resistant hybrids, the earworm and armyworm are vulnerably exposed in sorghum heads, especially as compared to the protection they receive from the corn ear. A search for lines possessing resistance to either or both species should be fruitful, especially because vast germplasm is available in both the converted and nonconverted forms of sorghum. Areas of control that show promise for limiting fall armyworms and corn earworms in corn should be applicable for sorghum.

Sorghum Webworm

The sorghum webworm, *Celama sorghiella* (Riley), is of particular importance throughout the humid South, and its range may extend as far north as Illinois and Nebraska (Young 1970). In Georgia, the earliest populations are usually on corn silks; thus, corn in this area may aid in the population buildup. The larvae feed on the ripening grain, consuming the individual kernels and leaving the outside hull intact. Webbing may occur along with the feeding. Losses caused by webworms are estimated at 0.5 percent (table 13). Of the three States (Arkansas, Illinois, and Texas) reporting losses in 1976 for the cooperative insect report, 0.5 percent was attributed to the sorghum webworm, or an average of 1.79 bushels per acre (U.S. Animal and Plant Health Inspection Service 1978).

Young and Teetes (1977) reported the economic threshold as an average of five larva per head. Since no data exist on the number of kernels one webworm larva may consume, this level seems rather high, and a closer look may be warranted. Since young larvae may begin feeding soon after pollination occurs, more small kernels would be consumed quicker than if the larvae became established a few days later. Current controls (table 15) center around the use of early plantings, keeping the webworm population in check with the use of insecticides, and plowing under crop residue.

Future controls (table 16) will certainly involve the use of early plantings (Hobbs et al. 1979) and the selective use of insecticides. Some promising pathogens have been experimented with and could be marketed in place of conventional chemical pesticides. Hamm et al. (1977) showed that the use of Dipel, a formulation of *Bacillus thuringiensis*, was effective. A braconid wasp, *Apanteles sorghiella* Mussebeck, parasitizes up to 38 percent of the larvae, although the parasites do not generally occur in sufficient numbers to prevent damaging infestations (Young 1970). Kairomone research should be a fruitful area of investigation since the webworm is gregarious in nature. Recent investigations of grain panicle types (open vs. compact) as a possible source of resistance showed that open heads appear more promising (Hobbs et al. 1979) than compact heads. If plant resistance could be located at even an intermediate level, it could be used easily with other controls. Studies of sex attractants or disruptants may be fruitful since this insect can be so explosive in building up large populations.

Mites

The twospotted spider mite and Banks grass mite are important pests of sorghum, and Owens et al. (1976) have reviewed their status. They are distributed from eastern New Mexico

Table 18.—Cooperative extension service pest-management programs in sorghum, by State, 1978[1]

State	Acres in program	State	Acres in program
Alabama	238	Nebraska	
Arizona	2,000	North Carolina	
Arkansas	500	Oklahoma	
Illinois	400	Texas	6,000
Mississippi		Virgin Islands	
Missouri	1,044		

[1]Some States indicated participation but did not include scouted acreage.

through the High Plains of Texas north through eastern Colorado and western Oklahoma, Kansas, and Nebraska. Mite damage appears as discoloration and premature death of the leaves, accompanied by large amounts of webbing. Young and Teetes (1977) do not list an economic threshold but state that treatment is necessary if, after the sorghum flowers, the population builds up rapidly away from the leaf midrib. Losses caused by mites are estimated at 0.5 percent annually (table 13). Only two States, Oklahoma and Texas, reported losses in 1976 for the cooperative insect report of 0.6 percent, or an average of 0.34 bushel per acre (U.S. Animal and Plant Health Inspection Service 1978). Miticides are presently the only control for damaging populations although there are some predators that appear to help control (table 15). However, alternative methods of suppressing populations are being investigated (Ehler 1974, Kattes and Teetes 1978). Resistance of the Banks grass mite to most registered miticides is cause for considerable concern in parts of Texas (Ward and Tan 1977).

The availability of alternative mite controls in the future (table 16) will depend on more research in such areas as cultural practices, mite biology, economic thresholds, and sorghum resistance. Some of the more promising areas appear to be the use of resistant "nonsenescing" types of sorghums as reported by Teetes (1976) and developing or refining cultural controls compatible with farming practices.

Summary

We will see a greater reduction in insect losses in sorghum than we will in corn. This statement is based on the advances made since the introduction in 1976 of greenbug-resistant hybrids and the potential for reducing losses caused by the midge. As soon as the new midge-resistant germplasm is utilized by the commercial companies, growers will have the flexibility needed to adjust plantings as dictated by moisture conditions and to avoid damaging populations of greenbugs. Lack of multiple pest resistance is one of the biggest hurdles we must overcome. This should be coupled with multigenic resistance for the various pests and then the "power-packed" components (resistance to more than one pest species and possessing several genes to prevent biotype development) would be provided as well as protecting our environment and cutting costs to the grower.

Seven States and the Virgin Islands participated in the 1978 pest-management program for sorghum (table 18). Many of the programs indicate deficiencies in reseach programs. Research on at least the most important sorghum insects in the United States must be given added emphasis in the future, especially in the number of scientists equivalent to the importance of this crop. An increase in scientific man-years for sorghum production insects research, which is presently only 1.8 for all of the U.S. Agricultural Research Service and 5.4 for the State Agricultural Experiment Stations, is needed.

CONCLUSIONS

The role of plant diversity in the management of production has been summarized for corn by Zuber (1975) and for sorghum by Harvey (1977). Zuber concluded that there is "no reason to 'push the panic button' with respect to genetic vulnerability in corn," but he cautioned that we should not become too complacent with the germplasm base. Harvey similarly concluded

Table 19.—Estimated trends in use of pest-control methods in grain crops, 1978-92

Control method	Probable use to 1992	Trend in use
Conventional chemicals:		
Insecticides	Major	Declining.
Herbicides	Major	Increasing.
Mechanical methods	Minor	Declining.
Biological methods:		
Parasites and predators	Minor	No change.
Bacteria	Minor	Increasing.
Viruses	Not significant	Increasing.
Pheromones	Not significant	No change.
Resistant varieties	Major	Increasing.
Pest genetics	Minor	Declining.
Cultural methods:		
Crop rotations	Minor	Declining.
Trap crops	Minor	No change.

Source: Headley 1979. Estimates made by 39 U.S. agriculture extension and research workers.

that "while there is a concentration of sorghum germplasm with a narrow genetic base, there are also evidences that both in commercial seed production and in breeding programs a diversity of germplasm is being introduced." We should realize that single-gene resistance planted over large localized areas can bring on problems similar to spraying large areas with one chemical; resistance in both corn and sorghum should be multipest and multigenic. As shown in table 19, resistant varieties will continue to be a major source of insect control.

The areas of insect control that should receive the greatest research efforts are those that will add little or no extra cost to the farmer and that are not harmful to the environment. Otherwise, we remove profit from the grower and add burdens to the taxpayer. As illustrated by Teetes (in press), control may often be simply attained by manipulating planting time and plant spacing. Nevertheless, many experts believe that chemicals will continue to be important for insect control in the future (Knipling 1978) (table 19). To overcome the dependence on chemicals, we need to integrate biological and cultural controls. But the research needs in these areas are great, and the research is time-consuming and expensive.

Latham (1975) reported that problems alone cannot justify a pest-management program—solutions to those problems are also essential. He stated "that until solutions are provided by research and extension, pest management programs have nothing to offer. While all answers are not required before a program is initiated, information to improve the current situation must be available."

Good (1977) indicated that a successful integrated pest-management program can be developed over the next 10 years, provided adequate financing is available. The projected acres of corn and sorghum in 1980 in IPM was 11.6 and 1.8 million, respectively, and by 1986, 38.9 and 10.9 million acres were projected. He also projected that, without IPM, an 11-percent increase in pesticide sales would occur. Most of the IPM programs involve scouting, determining economic thresholds, and then applying insecticides. Turpin and Maxwell (1976) showed that the farmer or grower is the primary decision maker in these instances. Therefore, we should supply the grower with as many techniques and methods that will enhance timely decisions to manage the insect pest to optimize production profits.

We have stressed the gaps that exist in basic research. One topic that has not been touched on is field testing. We must test the answers of basic research in small-field trials and subsequently in large-field or area tests before they are presented to the extension specialists or consultants for implementation. We have discussed several areas of research that might be fruitful and other areas that are lacking in research, but until they are tried and proven, industry and specialists will have to take some risks and try

some techniques that have not been thoroughly researched. Thus, it is imperative that the control components be tried and proven individually, then tried and proven in combination (because some are incompatible) with other integrated control components before a total package can be instituted in its complete form to manage the pest. This can be done for both corn and sorghum integrated control programs.

REFERENCES

Andrilenas, P. A.
1975. Farmers' use of pesticides in 1971—extent of crop use. U.S. Dep. Agric. Agric. Econ. Rep. 268, 25 pp.

Archer, T. L., and Musick, G. J.
1977a. Cutting potential of the black cutworm on field corn. J. Econ. Entomol. 70: 745-747.
1977b. Evaluation of sampling methods for black cutworm larvae in the field. J. Econ. Entomol. 70: 447-449.

Arnold, J. M.; Josephson, L. M.; Overton, W. R.; and Bennett, S. E.
1970. Cultural control of the southwestern corn borer. Tenn. Agric. Exp. Stn. Bull. 466, 12 pp.

Barry, D., and Darrah, L. L.
1978. Identification of corn germplasm resistant to the first generation of southwestern corn borer. J. Econ. Entomol. 71: 866-877.

Bartlett, R. J., and Chiang, H. C.
1977. Field studies involving the sex-attractant of the western and northern corn rootworm beetles. Environ. Entomol. 6: 853-861.

Bennett, S. E.; Josephson, L. M.; Stanley, W. W.; and Goddard, R. J.
1964. Southwestern corn borers in 1963. Tenn. Farm Home Sci. Prog. Rep. 49: 19-20.

Bottrell, D. G.
1971. Concepts for insect pest management in grain sorghums. Proc. Annu. Corn Sorghum Ind. Res. Conf., 26th, pp. 60-70.

Chiang, H. C.
1973. Ecological considerations in developing recommendations for chemical control of pests: European corn borer as a model. FAO Plant Prot. Bull. 21: 30-39.
1976. Assessing the value of components in a pest management system: maize insects as a model. FAO Plant Prot. Bull. 24: 8-17.
1978. Pest management in corn. Annu. Rev. Entomol. 23: 101-123.

Dickason, E. A.
1975. Insect management in corn and sorghum based on field monitoring teams. Proc. Annu. Corn Sorghum Ind. Res. Conf., 30th, pp. 73-80.

Dicke, F. F.
1977. The most important corn insects. Agronomy 18: 501-590.

Ehler, L. E.
1974. A review of the spider mite problem on grain sorghum and corn in West Texas. Tex. Agric. Exp. Stn. Bull. 1144, 15 pp.

Fox, A.; Eichers, T.; Andrilenas, P.; Jenkins, R.; and Black, H.
1968. Extent of farm pesticide use on crops in 1966. U.S. Dep. Agric Agric. Econ. Rep. 147, 23 pp.

Glass, E. H.
1975. Integrated pest management. Rationale, potential, needs, and implementation. Entomol. Soc. Am. Spec. Publ. 72-2, 141 pp.

Good, J. M.
1977. Integrated pest management—a look to the future. U.S. Ext. Serv. [Rep.] ESC 583, 18 pp.

Guthrie, W. D.; Dicke, F. F.; and Neiswonder, C. R.
1960. Leaf and sheath feeding resistance to the European corn borer in eight inbred lines of dent corn. Ohio Agric. Exp. Stn. Res. Bull. 860, 38 pp.

Hamm, J. J.; Wiseman, B. R.; and McMillian, W. W.
1977. Insect pathogens for controlling sorghum webworm on grain sorghum. Sorghum Newsl. 20: 90.

Hamm, J. J., and Young, J. R.
1971. Value of virus presilk treatment for corn earworm and fall armyworm control in sweet corn. J. Econ. Entomol. 64: 144-146.

Harvey, Paul H.
1977. Sorghum germplasm base in the U.S. Proc. Annu. Corn Sorghum Ind. Res. Conf., 32d, pp. 186-198.

Harvey, T. L., and Hackerott, H. L.
1969. Recognition of a greenbug biotype injurious to sorghum. J. Econ. Entomol. 62: 776-779.

Headley, J. C.
1979. Economics of pest control: have priorities changed? Farm Chem., April, pp. 55-57.

Henderson, C. F.; Kinzer, H. G.; and Thompson, E. G.
1966. Growth and yield of grain sorghum infested in the whorl with fall armyworm. J. Econ. Entomol. 59: 1001-1003.

Hill, R. E.; Carpino, D. P.; and Mayo, Z. B.
1978. Insect parasites of the European corn borer *Ostrinia nubilalis* in Nebraska from 1948-1976. Environ. Entomol. 7: 249-253.

Hill, R. E., and Gary, W. J.
1979. Effects of the microsporidium, *Nosema pyrausta*, on field populations of European corn borer in Nebraska. Environ. Entomol. 8: 91-95.

Hobbs, J. R.; Teetes, G. L.; Johnson, J. W.; and Wuensche, A. L.
1979. Management tactics for the sorghum webworm in sorghum. J. Econ. Entomol. 72: 362-363.

Huffaker, C. B., and Croft, B. A.
1978. Integrated pest management in the United States. Calif. Agric. 32: 6-7.

Johnson, J. W.
1975. Status of sorghums resistant to the greenbug, midge and the Banks grass mite. Bienn. Grain Sorghum Res. Util. Conf., 9th, pp. 50-58.

Johnson, J. W.; Rosenow, D. T.; and Teetes, G. L.
1973. Resistance to the sorghum midge in converted exotic sorghum cultivars. Crop Sci. 13: 754-755.

Kattes, D. H., and Teetes, G. L.
1978. Selected factors influencing the abundance of Banks grass mite in sorghum. Tex. Agric. Exp. Stn. Bull. 1186, 7 pp.

Kendrick, J. B., Jr.
1978. Agriculture's most important battle. Calif. Agric. 32: 3.

Klun, J. A., and Robinson, J. F.
1971. European corn borer moth: sex attractant and sex attraction inhibitors. Ann. Entomol. Soc. Am. 64: 1083-1086.

Knipling, E. F.
1966. "Introduction" to Pest Control by Chemical, Biological, Genetic, and Physical Means. A Symposium. U.S. Agric. Res. Serv. [Rep.] ARS 33-110, pp. 1-3.
1978. Strategic and tactical use of movement information in pest management. *In* C. R. Vaughn, W. Wolf, and W. Klassen (eds.), Radar, Insect Population Ecology, and Pest Management, pp. 41-57. NASA Conf. Publ. 2070.

Latham, E. E.
1976. Implementation of an integrated pest management program in sorghum. *In* Proceedings, U.S.-U.S.S.R. Symposium: The Integrated Control of the Arthropod, Disease and Weed Pests of Cotton, Grain Sorghum and Deciduous Fruit, pp. 42-49. Tex. Agric. Exp. Stn. Misc. Publ. 1276.

Lewis, L. C., and Lynch, R. E.
1976. Influence on the European corn borer of *Nosema pyrausta* and resistance in maize to leaf feeding. Environ. Entomol. 5: 139-142.

Lewis, W. J.; Jones, R. L.; Nordlund, D. A.; and Gross, H. R., Jr.
1975. Kairomones and their use for management of entomophagous insects. II. Mechanisms causing increased rate of parasitization by *Trichogramma* spp. J. Chem. Ecol. 1: 349-360.

Luckman, W. H.
1978. Insect control in corn—practices and prospects. *In* E. H. Smith and D. Pimentel (eds.), Pest Control Strategies, pp. 137-155. Academic Press, New York.

Luginbill, P.
1928. The fall armyworm. U.S. Dep. Agric. Tech. Bull. 35, 92 pp.

Lynch, R. E., and Lewis, L. C.
1976. Influence on the European corn borer of *Nosema pyrausta* and resistance in maize to sheath-collar feeding. Environ. Entomol. 5: 143-146.

Mitchell, E. R.; Jacobson, M.; and Baumhover, A. H.
1975. *Heliothis* spp.: disruption of pheromonal communication with (*Z*)-9-tetradecen-1-ol formate. Environ. Entomol. 4: 577-579.

National Academy of Sciences.
1969. Principles of plant and animal pest control. Vol. 3. Insect-pest management and control. Natl. Acad. Sci. Publ. 1695, 508 pp.
1975. Pest control: an assessment of present and alternative technologies. II. Corn/soybean pest control. 169 pp. The Academy, Washington, D.C.

Owens, J. C.; Ward, C. R.; and Teetes, G. L.
1976. Current status of spider mites in corn and sorghum. Proc. Annu. Corn Sorghum Ind. Res. Conf., 31st, pp. 38-64.

Pedigo, L. P.
1975. Insect threats and challenges to Iowa agroecosystems. Iowa State J. Res. 49: 457-466.

Poston, F. L.; TenEyck, G. R.; Wassom, C. E.; and Welch, S. M.
1978. Managing southwestern corn borer populations in irrigated Kansas corn. Kans. Agric. Exp. Stn. Res. Publ. 37, 15 pp.

Robinson, J. F.; Berry, E. C.; Lewis, L. C.; and Lynch, R. E.
1978. European corn borer: host-plant resistance and the use of insecticides. J. Econ. Entomol. 71: 109-110.

Schalk, J. M., and Ratcliffe, R. H.
1976. Evaluation of ARS progess on alternative methods of insect control. Host-plant resistance to insects. Bull. Entomol. Soc. Am. 22: 7-10.

Schweissing, F. C.
1969. Cultural practices for possible use in reducing spider mite damage in corn. Colo. State Univ. Exp. Stn. Prog. Rep. 69-72, 2 pp.
1973. Approaches to the management of the Banks grass mite on corn. Colo. State Univ. Exp. Stn. Prog. Rep. 73-41, 3 pp.

Scott, G. E., and Davis, F. M.
1976. Breeding for resistance to the southwestern corn borer. Proc. Annu. Corn Sorghum Ind. Res. Conf., 31st, pp. 118-128.

Scott, G. E.; Davis, F. M.; Beland, G. L.; Williams, W. P.; and King, S. B.
1977. Host-plant resistance is necessary for late-planted corn. Miss. Agric. For. Exp. Stn. Res. Rep. 3, 4 pp.

Sekul, A. A., and Sparks, A. N.
1976. Sex attractant of the fall armyworm moth. U.S. Dep. Agric. Tech. Bull. 1542, 6 pp.

Smith, R. F.
1978. Development of integrated pest management in California. Calif. Agric. 32: 5.

Sparks, A. N.; Carpenter, J. E.; Klun, J. A.; and Mullinix, B. G.
1979. Field responses of male *Heliothis zea* (Boddie) to pheromonal stimuli and trap design. J. Ga. Entomol. Soc. 14: 318-325.

Sparks, A. N., and Mitchell, E. R.
1979. Economic thresholds of *Heliothis* spp. on corn. *In* Economic Thresholds and Sampling of *Heliothis* Species on Cotton, Corn, Soybeans and Other Host Plants, pp. 51-56. South. Coop. Ser. Bull. 235.

Starks, K. J.; Burton, R. L.; Teetes, G. L.; and Wood, E. A., Jr.
1976. Release of parasitoids to control greenbugs on sorghum. U.S. Agric. Res. Serv. [Rep.] ARS-S-91, 12 pp.

Summers, C. G.; Coviello, R. L.; Pendry, W. E.; and Bushing, R. W.
1976. Effect of sorghum midge on grain sorghum production in the San Joaquin Valley relative to date of planting and plant spacing. Hilgardia 44: 127-140.

Teetes, G. L.
1976. Integrated control of arthropod pests of sorghum. *In* Proceedings, U.S.-U.S.S.R. Symposium: The Integrated Control of the Arthropod, Disease and Weed Pests of Cotton, Grain Sorghum and Deciduous Fruit, pp. 24-41. Tex.

Agric. Exp. Stn. Misc. Publ. 1276.

In Press. The environmental control of insects using planting times and plant spacing. *In* Handbook Series in Agriculture. Section D. Pest Management. CRC Press Inc.

Teetes, G. L.; Schaefer, C. A.; Gibson, J. R.; McIntyre, R. C.; and Latham, E. E.

1975. Greenbug resistance to organophosphorous insecticides on the Texas High Plains. J. Econ. Entomol. 68: 214-216.

Teetes, G. L., and Wiseman, B. R.

1979. Economic thresholds of *Heliothis* species in sorghum. *In* Economic Thresholds and Sampling of *Heliothis* Species on Cotton, Corn, Soybeans, and Other Host Plants, pp. 57-61. South. Coop. Ser. Bull. 235.

Texas Agricultural Extension Service.

1979. Insect and mite pests of grain sorghum—management approaches. Tex. Agric. Ext. Serv. [Rep.] B-1220, 24 pp.

Thomas, J. G.

1969. The sorghum midge and its control. Tex. Agric. Exp. Stn. Prog. Rep. 2130, 5 pp.

Turpin, F. T.

1974. Threshold research on corn. Proc. North Cent. Branch Entomol. Soc. Am. 29: 61-65.

Turpin, F. T., and Maxwell, J. D.

1976. Decision-making related to use of soil insecticides by Indiana corn farmers. J. Econ. Entomol. 69: 359-362.

U.S. Agricultural Research Service.

1976. ARS national research program. NRP No. 20240. Insect control—grains, forages, sugar crops and oilseeds. 202 pp. The Service, Washington, D.C.

U.S. Animal and Plant Health Inspection Service.

1976. Distribution of the southwestern corn borer, *Diatraea grandiosella*. Coop. Plant Pest Rep. 1: 44.

1978. Coop. Plant Pest Rep. 3: 91-117.

U.S. Department of Agriculture.

1979. Agricultural statistics, 1979. 603 pp. The Department, Washington, D.C.

Ward, C. R., and Tan, F. M.

1977. Organophosphate resistance in the Banks grass mite. J. Econ. Entomol. 70: 250-252.

Watson, T. F.; Moore, L.; and Ware, G. W.

1975. Practical insect pest management, a self-instructing manual. 196 pp. W. H. Freeman, San Francisco.

Wilde, G.

1978. Corn rootworm control in Kansas. Kans. Agric. Exp. Stn. Bull. 616, 15 pp.

Wiseman, B. R., and Davis, Frank.

1979. Plant resistance to the fall armyworm. Fla. Entomol. 62: 123-130.

Wiseman, B. R.; Gross, H. R., Jr.; and McMillian, W. W.

1978. Seasonal distribution of the sorghum midge and its hymenopteran parasites, 1975-77. Environ. Entomol. 7: 820-822.

Wiseman, B. R., and McMillian, W. W.

1969. Relationship between planting date and damage to grain sorghum by the sorghum midge, *Contarinia sorghicola* (Diptera: Cecidomyiidae) in 1968. J. Ga. Entomol. Soc. 4: 55-58.

Wiseman, B. R.; McMillian, W. W.; and Widstrom, N. W.

1972. Tolerance as a mechanism of resistance in corn to the corn earworm. J. Econ. Entomol. 65: 835-837.

1973. Registration of SGIRL-MR-1 sorghum germplasm. Crop Sci. 13: 398.

Wood, E. A., Jr.

1971. Designation and reaction of three biotypes of the greenbug cultured on resistant and susceptible species of sorghum. J. Econ. Entomol. 64: 183-185.

Young, W. R.

1970. Sorghum insects. *In* J. S. Wall and W. M. Ross (eds.), Sorghum Production and Utilization, pp. 235-287. AVI Publishing, Westport, Conn.

Young, W. R., and Teetes, G. L.

1977. Sorghum entomology. Annu. Rev. Entomol. 22: 193-218.

Zuber, M. S.

1975. Corn germ plasm base in the U.S.—is it narrowing, widening, or static? Proc. Annu. Corn Sorghum Ind. Res. Conf., 30th, pp. 277-286.

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